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EDGEWOOD ARSENAL TECHNICAL REPORT
EM-TR-76008

APPLICATIONS OF SUPPRESSIVE SHIELDING IN HAZARDOUS OPERATION PROTECTION

INTERIM REPORT

by

Bruce W. Jezek
David J. Katsanis
Richard G. Thresher

Manufacturing Technology Directorate

August 1975

DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

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A new kind of protective barricade is being developed by Edgewood Arsenal for use in protecting equipment and personnel that are performing hazardous operations during the manufacturing of munitions in Army ammunition plants. This protective structure; i.e., suppressive shield, provides the protection from the dangerous effects of an explosive detonation. The suppressive shield consists of a series of vented panels in a framework. The vented panels are fabricated from a combination of perforated plates, spaced angle irons, louvred plates and/or wire screening; the specific arrangement depends on the hazard to be suppressed. Suppressive shields are designed to attenuate the explosive blast pressure and fireball and prevent any fragments from excaping the structure.

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PREFACE

The work described in this interim report was authorized under MM&T Project 5751264, Advance Technology for Suppressive Shielding of Hazardous Production and Supply Operation. This work was started in 1973 and is continuing.

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I. INTRODUCTION

Individual buildings in ammunition plants are widely dispersed in accordance with DOD and Army safety regulations (AR 385-64, DOD 5154.47, TM 9-1300-206). The large distance between these buildings is required for the protection of operating personnel in adjacent buildings and to reduce facility damage to an acceptable level in the event of an accidental explosion. The current policy used to design manufacturing facilities at the numerous Army ammunition plants is concrete barricades, cubicle structures, and shelters. A typical cubicle is shown in Figure 1. Laced, reinforced concrete barricades and structures constructed in accordance with a joint Army, Navy, and Air Force technical manual, TM 5-1300, entitled "Structures to Resist the Effects of Accidental Explosions" contain the sensitive explosive materials or processing equipment.

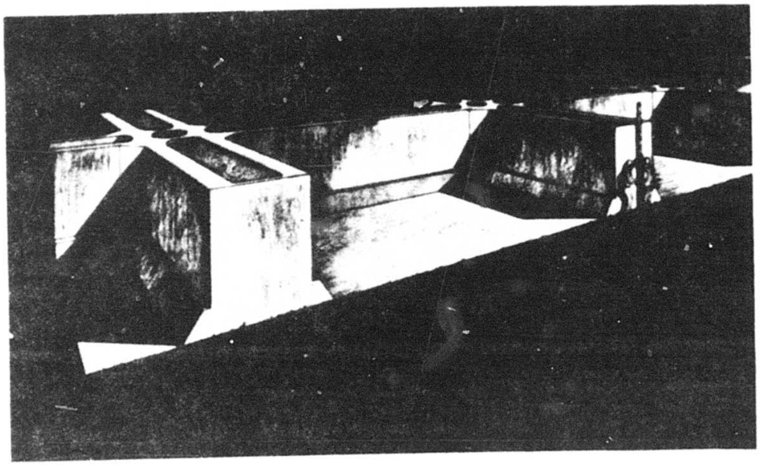

Figure 1. Typical Cubicle Structure

Barricades are used to prevent propagation of the explosion from one area to the next by separating the quantities of potentially detonable materials or hazardous process steps; they do not prevent leakage of the high blast pressures or wide dispersal of damaging primary and secondary fragments generated when a detonation occurs. Shelters, on the other hand, are designed to totally contain the effects of an explosion. They must be designed to withstand the very high overpressures generated by reflections from their solid surfaces.

Typically, barricades and shelters are both fixed plant installations and are a severe constraint to plant rearrangement which may be necessary as

a result of process changes. In addition, this places undesirable constraints on the production output of a facility and requires higher capital investments to attain a desired production objective and in many cases is the limiting factor in the rate of production attainable. To avoid these problems, plant designers have resorted to greater separation distances and special orientation of buildings to minimize the need for laced, réinforced concrete barricades and shelters. This, of course, necessitates greater initial commitments in real estate and, on a long term operational basis, is the cause for higher operating costs due to extended utilities services and the need to transport personnel and material greater distances to and from work stations.

Suppressive shields, if successful, offer an opportunity to reduce production costs and new plant construction costs and to avoid inflexible plant arrangements.

A suppressive shield design was conceived in 1971 in response to a requirement for a total containment enclosure to be placed on a 4.2" White Phosphorus mortar projectile loading line. The lack of space and the need to have operators work within five feet of the shields made it necessary to think in terms of minimum wall thickness and attenuation of blast pressures and confinement of fragments and fireball in the shield. To meet this need, an enclosure was provided which would attach to the existing structure. It was composed of panels made of layers of steel grating, perforated and louvered sheets arranged and spaced to permit venting of blast overpressures and prevent "line of sight" openings through which fragments could pass.

The panels were installed in a sturdy framework and tested against the maximum credible incident. The total thickness of metal facing the fragmentation challenge was 5/8"; the effective venting area was 30-40 percent of the exposed surface. Tests indicated satisfactory performance of this shield in achieving the desired suppression. This demonstration of a shield providing fragment containment coupled with blast pressure and fireball suppression stimulated high interest in its potential application to a variety of ammunition processing, transportation, and storage environments.

II. SUPPRESSIVE SHIELD SYSTEMS ENGINEERING

Typical suppressive shields (Figure 2) consist of two basic components - a framework and the suppressive panels. The exploded view illustrates a panel section of a typical multi-layered suppressive shield. The interior layer of nested angle irons is the primary fragment stopping device. The layers of steel perforated sheet and the outer louvered sheet act to reduce blast overpressure. The wire screening dissipates the heat from the explosion. By selection of the appropriate arrangement of panels, shields can be "tailor-made" to suit the hazard situation. The panel components selected to meet the hazard challenge are mounted into a structure to enclose the operation. Munition entry and exit ports and closures are provided to seal the shield

during the hazardous processing. Enclosures are mounted to the floor by methods which allow their ready removal.

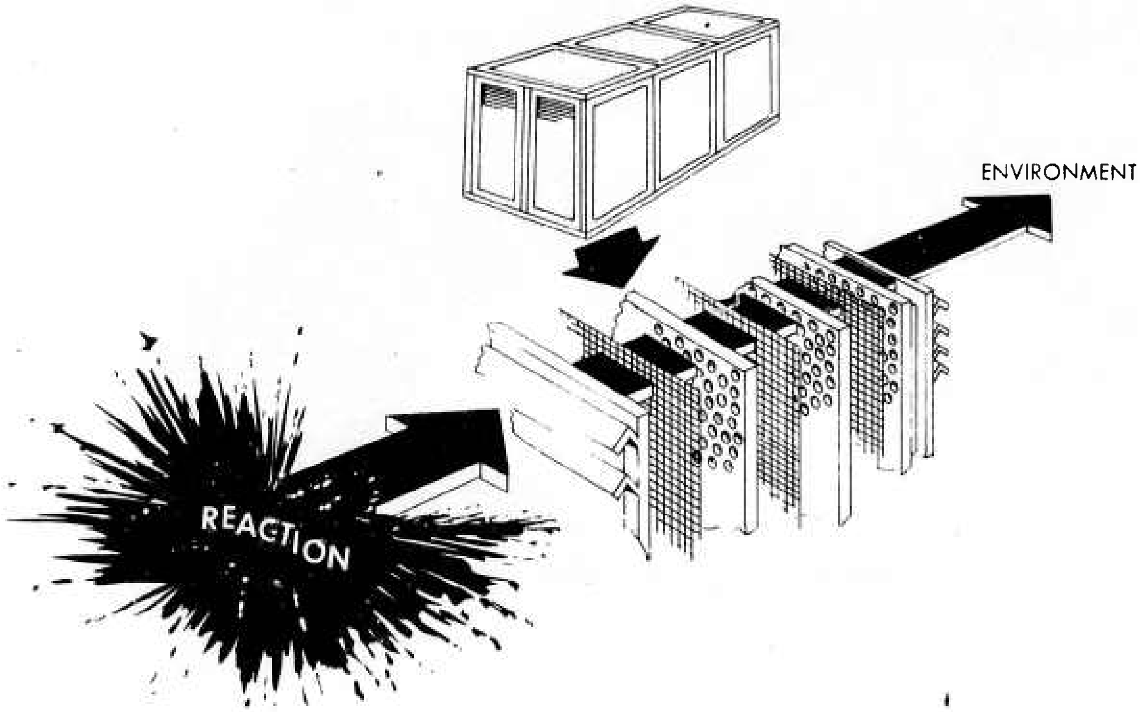

Figure 2. Suppressive Shield Functions

Suppressive shields are housed in lightweight, low cost outer buildings as shown schematically in Figure 3. The arrangement of the munitions production line defines operator work stations, position of equipment, and location of building walls and roof. These are used to determine safe pressure levels which, in turn, fix the venting characteristics of the suppressive shield. Analysis of pressure estimates is used to determine loads on the suppressive shield panels and structure. The preliminary design thus generated is checked to verify adequate fragment and flame suppression. Angles, plates, or screens are added to the panel configuration to insure required protection against fragment or thermal hazards. Thus, the entire system is designed so as to preclude damage to the building or injury to operation personnel in the event a detonation occurs. This concept of use, coupled with a one-explosive event life cycle, permits the acceptability of plastic deformation of the suppressive shield during the detonation and constitutes the basis for the design of suppressive shields.

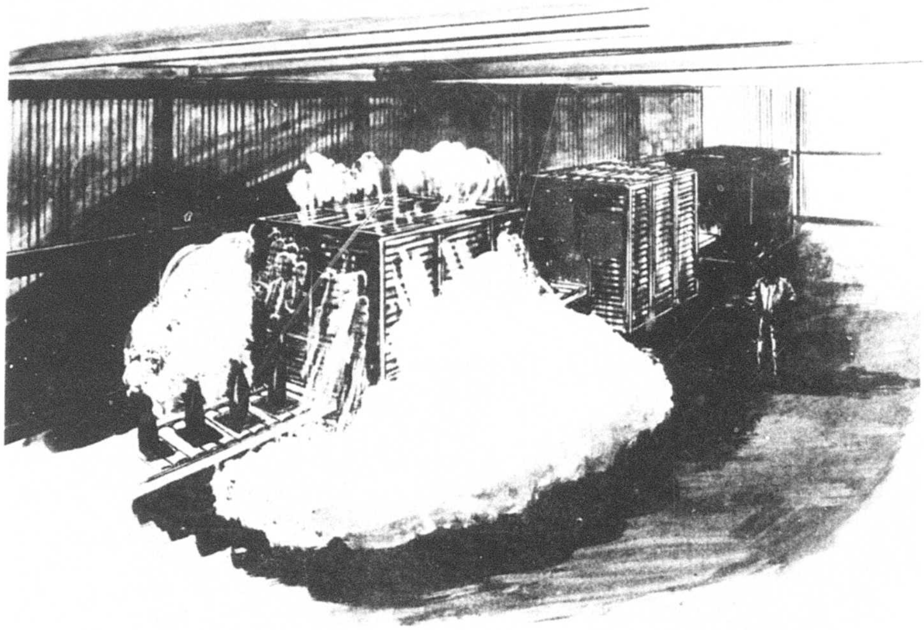

Figure 3. Chemical Agent Munition Disposal System (CAMDS) Suppressive Shield

III. SUPPRESSIVE SHIELD DESIGNS

Three full scale suppressive shield systems have been designed, fabricated, and tested for application to the following areas:

- o Chemical Ammunition Disposal
- o Ammunition Loading and Assembly
- o Explosive Ordnance Disposal

The first of the three shielding systems involved design, fabrication, and test of a full scale prototype to test the applicability of suppressive shielding to house hazardous disassembly operations involved in a Chemical Ammunition Disposal System (CAMDS). The major system components for the CAMDS are a shield enclosure, plenum chamber, and outer weather structure. The critical design requirement of the operational system is that it must provide complete confidence that if a detonation occurs, no toxic materials will be released outside the disposal facility.

The second project involves a suppressive enclosure for shielding selected hazardous operations on 81mm high explosive mortar lines being installed at two ammunition plants. Figure 4 illustrates the 81mm structure. Munitions would be processed in this enclosure and explosive machining operations performed simultaneously on two mortar rounds. The hazard is sufficiently great to warrant total enclosure and full automation of this station.

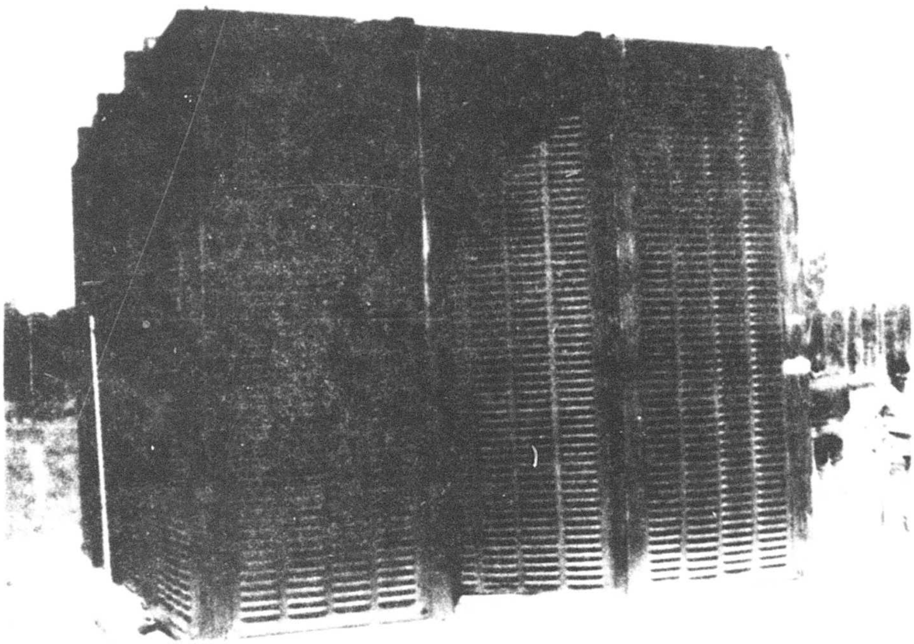

Figure 4. Suppressive Shield for Use in 81MM Mortar Production Assembly Line

Qualification tests for the shield included simultaneous detonation of three rounds, oriented to simulate the operating tooling arrangement.

The structure withstood 50 psi incident blast pressure, successfully contained primary and secondary fragments, and attenuated the explosive fireball. Plastic yielding of the structural frame occurred indicating that we are approaching the design goal. However, this shield was designed to contain the simultaneous detonation of two rounds and it successfully contained the effects of six rounds, indicating that the design was not optimized. Upon safety approval of the exit and entry doors, it will be the first suppressive-type operational shield to be safety approved for munition assembly operations.

Figure 5 shows a trailer-mounted six feet long, six feet in diameter suppressive shield capable of safely containing the effects of detonation of a clandestine device containing twenty pounds of high explosive. The shield is transportable so that explosive ordnance disposal personnel can move it to the device and safely remove it through populated areas without endangering the inhabitants. The walls and ends consist of an inner layer of simple 3/16" x 3" x 3" angle iron backed up by two layers of 3/16" thick mild steel perforated sheet spaced 1/2" apart. A small (18" x 18") steel door at the rear of the enclosure is used to insert or remove an explosive device which is centrally supported and restrained on a rack while being transported. The system has been tested against a twenty pound charge of Composition C-4 and a one pound charge of the same material in a simple pipe bomb (L/D is 6.7 to 1). There was no fragment penetration beyond the inner layer of angle iron and the blast overpressure was attenuated 78 percent for the pipe bomb, within 18 inches of the outer surface of the shield.

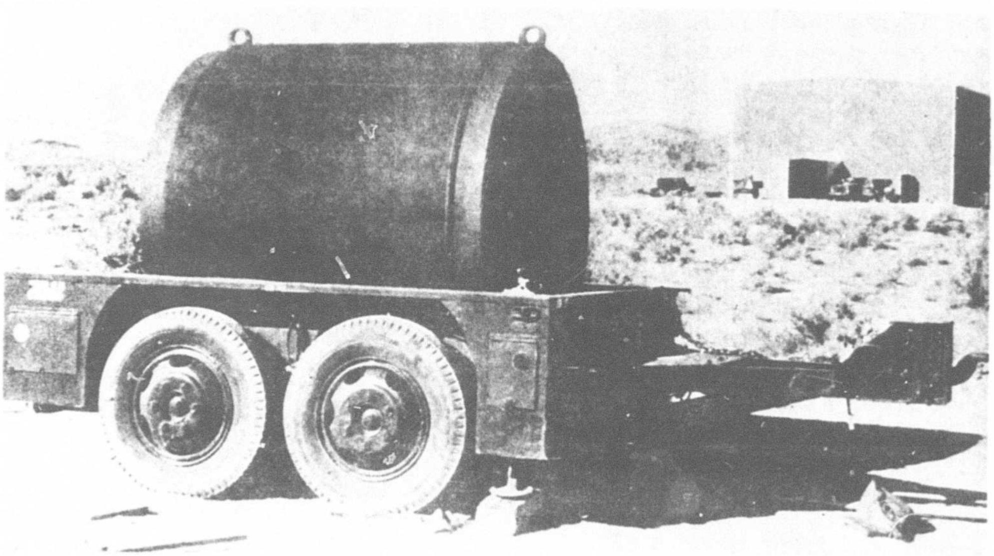

Figure 5. Suppressive Shield for Navy Explosive Ordnance Disposal

The shield testing program has included chemical, incendiary, and high explosive ammunition. The explosive content of the test munitions to date has ranged from fractions of a pound to twenty pounds and blast pressures from 50-1200 pounds per square inch. Every indication is that as the charge is increased, the suppressive effects of the shield are more pronounced. Blast scaling laws have been shown applicable as we proceeded from subscale to full scale testing.

Summarized below are the suppressive shield functional characteristics based on the over 200 laboratory, subscale, and full scale tests we have conducted to date.

Hazard Parameter	Degree of Attenuation
Fragmentation	100%
Blast Overpressure	60-80%
Impulse	60-80%
Shock Wave Arrival Time	Delayed by 50%
Fireball Diameter	70-90%

After examining the test results and witnessing some of the experimental demonstrations of the shield, engineers from the Army's Frankford Arsenal indicated an interest in an application for one of their problem areas; that is, the transport of high explosive primers while they are being processed in small arms ammunition production plants. The primers were being transported tightly sandwiched between two solid plates. As a result when one primer detonated, the entire contents exploded and the plates on either side of the primers blew apart. This situation has occurred at several plants and damage in each instance ranged from $100,000 to over $300,000. The mere replacement of the lexan plate that covered the top of the primers by a thin .020" thick perforated aluminum sheet was sufficient to prevent sympathetic detonation of more than one primer when one was initiated and only 50 percent of the remaining primers when six primers in the tray were initiated. It completely relieved the fragment hazard associated with the primer tray. As a result, this type of primer tray is being adapted for use in LAP (Load, Assembly, Pack) of small arms ammunition. Figure 6 illustrates the primer trays covered with lexan and suppressive screening.

There are several other areas in which suppressive type shielding may have application. For example, shields can be used in EOD operations. An explosive device or dud which cannot be moved can be detonated in place with a shield over the munition. In that case, there is no need for shielding the personnel or equipment. In other situations, it may be impractical to put a shield over the explosive. Then personnel and equipment can be shielded. In addition, suppressive shielding could be used as a bomb shelter on the battlefield.

It may be feasible to shield either individual rounds or groups of rounds in storage to prevent sympathetic detonations where one detonated round could cause an entire storage facility to be destroyed as a result of detonation propagation.

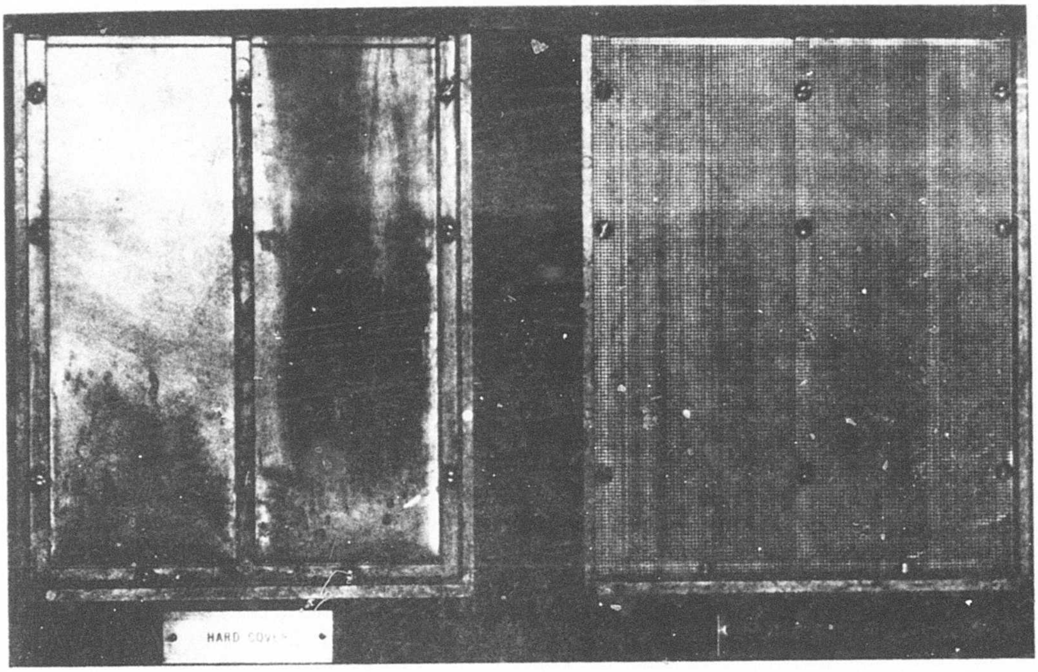

Figure 6. Suppressive Transport Tray for 5 56MM Primers

IV. ENGINEERING DEVELOPMENT PROGRAM

The suppressive shield engineering program is directed toward early safety approval of the use of this novel protective barrier to the full gamut of ammunition manufacturing operations. This will be accomplished by the development of seven category shields as defined in the following table.

HAZARD PARAMETERS

Category No.	Incident Blast Pressure	Fragmentation
1	Extra high (500-1200 psi)	Severe (major caliber projectiles)
2	High (200-500 psi)	Moderately severe to severe (anti-personnel type projectiles)
3	High (200-500 psi)	Light (munition components)
4	Moderate (50-200 psi)	Moderate to severe (munition components)
5	Light (50 psi)	Light (lightweight metal/plastic) flame attenuation necessary
6	Ultra high (500-2000 psi)	Light to moderate
7	Moderate (50-200 psi)	Severe (chemical munitions)

Further, an in-depth technological program will be conducted to accurately predict shield design parameters for blast, fire, fragment, or chemical hazard conditions, and to set these forth in a design handbook to allow a plant engineer to design a highly cost effective suppressive shield. This segment of the engineering program is to develop technology in the following areas:

a. Blast phenomena: This will define and quantify the pressures and forces that are created within a shield due to an explosion.

b. Design loads: This effort will provide the designer with the capability of translating the detonation phenomena to design load in a given structure.

c. Fragment characteristics: The primary and secondary fragments resulting from an explosion will be defined to determine the material thickness necessary to prevent fragments from escaping the suppressive structure.

d. Structural response: The loads imposed on the structure including impulsive, dynamic, and quasi-static will be used to establish the structural response. Natural frequencies, stresses, and strains will be computed to determine the advantageous effects of venting the blast pressure.

e. Fireball: This effort will describe the fireball of an explosive detonation. The high temperature and short duration of the fireball is extremely hazardous to personnel in close proximity of the fireball.

f. Determine shield attenuation characteristics: This is the culmination of the suppressive structures technology development; the development of predictive techniques to accurately define the attenuation characteristics of suppressive designs.

Initial efforts have addressed the development of technology to define the blast attenuation phenomena occurring within the suppressive structure. This investigation consists of shock tube tests, subscale suppressive panel tests, and the development of predictive analytical techniques. The shock tube is used to generate a pressure pulse simulating that which occurs in an explosive detonation. A 10cm shock tube has been used to conduct these tests. (See Figure 7.) Various suppressive panel configurations are inserted in the shock tube and the pressure levels in front of and behind the panel measured.

The vent area was varied between 10 and 50 percent and pressures ranged from 50 psi to 200 psi. The results to date are shown in Figure 8 for a single perforated plate. These results revealed that the percent pressure attenuation was unaffected by the input pressure level. Future tests will be conducted with multiple layers of perforated plates and other various combinations of structural members.

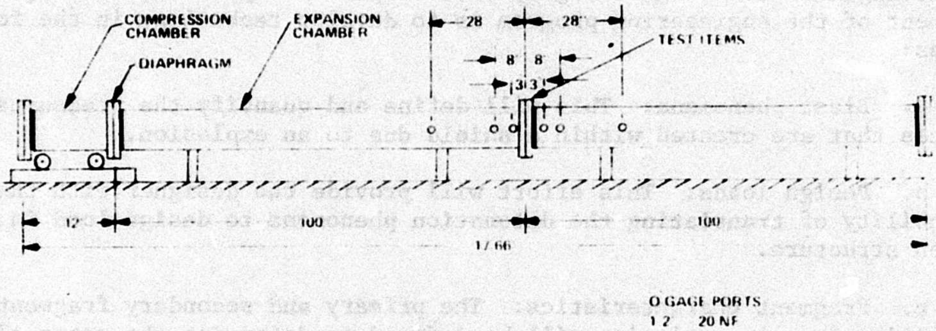

Figure 7. Shock Tube Test Setup

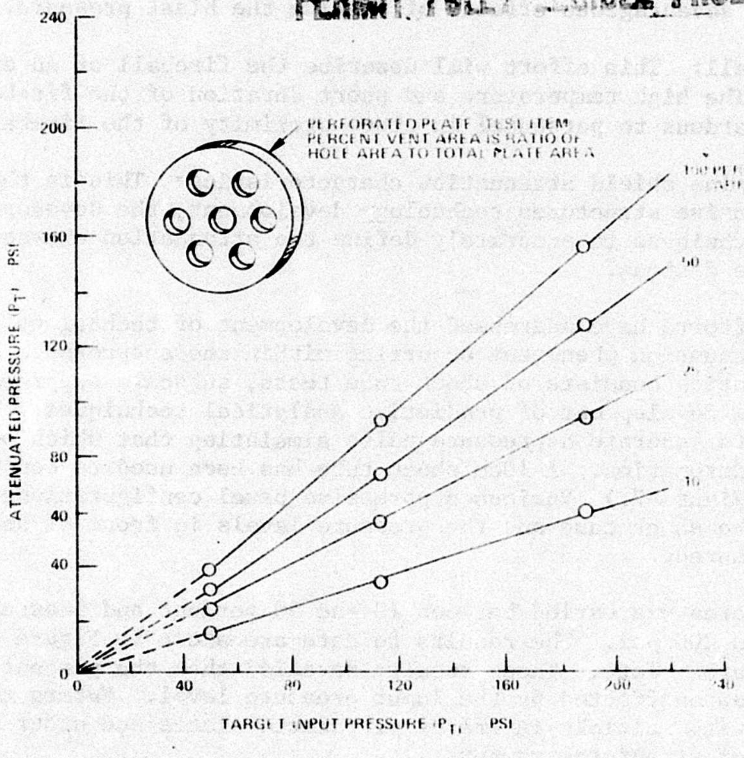

Figure 8. Input Pressure Versus Attenuated Pressure for Different Vent Areas

A series of subscale panel test fixtures were fabricated to evaluate candidate panel configurations for the category shields previously described. These fixtures were cubical in shape, approximately 2.5 feet per side. Pressure transducers were mounted both internal and external to the structure. The internal pressure transducers recorded the reflected blast pressures and the gas pressure build up as a function of time. These data were essential to assess the structural loading and subsequent response of the structure to these loads. Of major importance is the attenuation of these forcing functions caused by venting the structure. Test results indicate that the gas pressure build up inside the structure after the shock wave has passed (termed quasi-static) has the same magnitude as that experienced in a closed (unvented) pressure vessel; however, the duration of the pressure is reduced 35 percent. This will appreciably reduce the size of the structure to withstand these pressures.

Additionally, external pressure transducers were used to record the attenuation in the blast pressure caused by the vented structure. A series of transducers were mounted along the ground at varying distances from the structure. All transducers indicated significant pressure attenuation. The percent pressure attenuation was found to vary as a function of distance. The pressure was attenuated at the scaled safe inhabited building distance by 20 percent.

These subscale panel fixture tests are continuing and will be compared to shock tube and theoretical results to verify the shock tube data and to develop analytical techniques to predict the performance of future suppressive shield designs.

As the suppressive shielding engineering program progresses, additional full scale tests will be conducted in the seven category shields with all data input to the applied technology development phase. Analytical studies in gas dynamics, structural response, and heat transfer will also be performed.

V. POTENTIAL COST SAVINGS

It is difficult, at this time, to make a true assessment of the cost of the suppressive structures compared to the conventional reinforced concrete construction since we have not had the opportunity of providing an optimized plant design or plant arrangement based on the utilization of suppressive shields throughout. We believe that the use of suppressive shields will make it possible to utilize lightweight structures to house the ammunition plant operations. We know that because of the reduced wall thicknesses and suppressive capabilities that are possible with suppressive shielding, their use would facilitate storage of explosive materials in smaller quantities in reduced space. This should further, even under today's conditions, allow smaller intraline and inhabited building distances to be utilized. Production lines requiring many barricaded operations could be reduced in length.

Suppressive shields are made from standard structural shapes and fabricated sheet materials and they are joined by routine welding or bolting operations. When applied to entire production lines, utilization of standardized production fabrication techniques can be brought into play.

VI. SUMMARY

The feasibility of constructing effective suppressive shields has been demonstrated on a full scale test basis. Suppressive shields have the potential to provide added protection against loss of life and property while ammunition is being shipped, stored, demilitarized, or disposed.

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